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यांत्रिक कम्पन के लिए शब्दावली

(पहला पुनरीक्षण)

Indian Standard

VOCABULARY ON VIBRATION AND SHOCK

(First Revision)

ICS 17.160;01.040.17

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

May 2000

Price Group 11

Mechanical Vibration and Shock Sectional Committee, LM 04

NATIONAL FOREWORD

This Indian Standard (First Revision) which is identical with ISO 2041 : 1990 'Vibration and shock — Vocabulary', issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of Mechanical Vibration and Shock Sectional Committee and approval of the Light Mechanical Engineering Division Council.

This standard was first published in 1985. This first revision has been taken up to align with the latest version of ISO 2041 which has been technically revised in 1990.

The text of ISO Standard has been approved as suitable for publication as Indian Standard without deviations. In the adopted standard, certain conventions are not identical to those used in Indian Standards. Attention is especially drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a full point (.) as the decimal marker.

Indian Standard
VOCABULARY ON VIBRATION AND SHOCK
(First Revision)

Scope

This International Standard defines terms in English relating to vibration and shock. An alphabetical index is also provided.

1 General

1.1 displacement; relative displacement : A vector quantity that specifies the change of position of a body, or particle, with respect to a reference frame.

NOTES

1 The reference frame is usually a set of axes at a mean position or a position of rest. In general, the displacement can be represented by a rotation vector, a translation vector, or both.

2 A displacement is designated as **relative displacement** if it is measured with respect to a reference frame other than the primary reference frame designated in the given case. The **relative displacement** between two points is the vector difference between the displacements of the two points.

1.2 velocity; relative velocity : A vector that specifies the time-derivative of displacement.

NOTES

1 The reference frame is usually a set of axes at a mean position or a position of rest. In general, the velocity can be represented by a rotation vector, a translation vector, or both.

2 A velocity is designated as **relative velocity** if it is measured with respect to a reference frame other than the primary reference frame designated in a given case. The **relative velocity** between two points is the vector difference between the velocities of the two points.

1.3 acceleration : A vector that specifies the time-derivative of velocity.

NOTES

1 The reference frame is usually a set of axes at a mean position or a position of rest. In general, the acceleration can be represented by a rotation vector, a translation vector, or both.

2 An acceleration is designated as **relative acceleration** if it is measured with respect to a reference frame other than the inertial reference frame designated in a given case. The **relative acceleration** between two points is the vector difference between the accelerations of the two points.

3 Various self-explanatory modifiers, such as peak, average, and r.m.s. (root-mean-square), are often used. The time intervals over which the average or root-mean-square values are taken should be indicated or implied.

4 Acceleration may be oscillatory, in which case simple harmonic components can be defined by the acceleration amplitude (and frequency), or random, in which case the r.m.s. acceleration (and bandwidth and probability density distribution) can be used to define the probability that the acceleration will have values within any given range. Accelerations of short time duration are defined as transient accelerations. Non-oscillatory accelerations are defined as sustained accelerations, if of long duration, or as acceleration pulses, if of short duration.

1.4 acceleration of gravity, *g* **:** The acceleration produced by the force of gravity at the surface of the Earth. It varies with the latitude and elevation of the point of observation.

NOTES

1 By international agreement, the value 980,665 m/s^2 (= 980,665 cm/s^2 = 386,089 in/s^2 = 32,174 0 ft/s^2) has been chosen as the standard acceleration due to gravity (g).

2 Acceleration magnitude is frequently expressed as a multiple of g.

1.5 jerk : A vector that specifies the time-derivative of acceleration.

1.6 inertial reference system; inertial reference frame: A coordinate system in which the laws of inertia (classical mechanics) are valid.

NOTE — An inertial reference system signifies a coordinate system which is fixed in space and, thus, not accelerating.

1.7 inertia force; inertial force : The reaction force exerted by a mass when it is being accelerated.

1.8 oscillation : The variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than some mean value.

1.9 sound :

(1) The sensation of hearing excited by an acoustic oscillation.

(2) Acoustic oscillation of such a character as to be capable of exciting the sensation of hearing.

(3) An oscillation in pressure, stress, particle velocity, etc., in a medium with internal forces.

1.10 acoustics : The science and technology of sound, including its production, transmission and effects.

1.11 environment : The aggregate, at a given moment, of all external conditions and influences to which a system is subjected. [See *induced environment* (1.12) and *natural environment* (1.13).]

1.12 induced environment : Those conditions external to a system generated as a result of the operation of the system.

1.13 natural environment : Those conditions generated by the forces of nature and the effects of which are experienced by a system when it is at rest as well as when it is in operation.

1.14 preconditioning : The climatic and/or mechanical and/or electrical treatment procedure which may be specified for a particular system so that it attains a defined state.

1.15 conditioning : The climatic and/or mechanical and/or electrical conditions to which a system is subjected in order to determine the effect of such conditions upon it.

1.16 excitation; stimulus : An external force (or other input) applied to a system that causes the system to respond in some way.

1.17 response (of a system) : A quantitative expression of the output of the system.

1.18 transmissibility : The non-dimensional ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude. The ratio may be one of forces, displacements, velocities or accelerations.

1.19 overshoot (undershoot) : If the output of a system is changed from a steady value A to a steady value B by varying the input, such that value B is greater (less) than A, then the response is said to overshoot (undershoot) when the maximum (minimum) transient response exceeds (is less than) value B.

NOTE — The difference between the maximum (minimum) transient response and the value B is the value of the overshoot (undershoot).

1.20 system : An aggregate of the relevant and/or constituent parts of a device.

1.21 linear system : A system in which the response is proportional to the magnitude of the excitation.

NOTE — This definition implies that the dynamic properties of each element in the system can be represented by a set of linear differential equations with constant coefficients, and that the principle of superposition can be applied to the system.

1.22 mechanical system : An aggregate of matter comprising a defined configuration of mass, stiffness and damping.

1.23 foundation : A structure that supports a mechanical system. It may be fixed in a specified reference frame or it may undergo a motion that provides excitation for the supported system.

1.24 seismic system : A system consisting of a mass attached to a reference base by one or more flexible elements. Damping is normally included.

NOTES

1 Seismic systems are usually idealized as single degree-of-freedom systems with viscous damping.

2 The natural frequencies of the mass as supported by the flexible elements are relatively low for seismic systems associated with displacement or velocity pick-ups, and are relatively high for acceleration pick-ups, as compared with the range of frequencies to be measured.

3 When the natural frequency of the seismic system is low relative to the frequency range of interest, the mass of the seismic system may be considered to be at rest over this range of frequencies.

1.25 equivalent system : A system that may be substituted for another system for the purpose of analysis.

NOTE — Many types of equivalence are common in vibration and shock technology :

a) equivalent stiffness;

b) equivalent damping;

c) torsional system equivalent to a translational system;

d) electrical or acoustical system equivalent to a mechanical system, etc.

1.26 degrees of freedom : The number of degrees of freedom of a mechanical system is equal to the minimum number of independent generalized coordinates required to define completely the configuration of the system at any instant of time.

1.27 single degree-of-freedom system : A system requiring but one coordinate to define completely its configuration at any instant.

1.28 multi-degree-of-freedom system : A system for which two or more coordinates are required to define completely the configuration of the system at any instant.

1.29 continuous system; distributed system : A system having an infinite number of possible independent configurations.

NOTE — The configuration of a continuous system is specified by a function of a continuous spatial variable, or variables, in contrast to a discrete or lumped parameter system which requires only a finite number of coordinates to specify its configuration.

1.30 centre of gravity : That point through which passes the resultant of the weights of its component particles for all orientations of the body with respect to a gravitational field.

NOTE — If the field is uniform, the centre of gravity coincides with the *centre of mass* (1.31).

1.31 centre of mass : The point associated with a body which has the property that an imaginary particle placed at this point with a mass equal to the mass of a given material system has a first moment with respect to any plane equal to the corresponding first moment of the system.

1.32 principal axes of inertia : For each set of Cartesian coordinates at a given point, the values of the six moments of inertia of a body I_{xixj} $(i, j = 1, 2, 3)$ are in general unequal; for one such coordinate system, the products of inertia I_{xixj} $(i \neq j)$ vanish. The values of I_{xixj} $(i = j)$ for this particular coordinate system are called the **principal moments of inertia** and the corresponding coordinate directions are called the **principal axes of inertia**.

NOTES

1 $I_{xixj} = \int xixj \ \mathrm{d}m$ for $i \neq j$

$I_{xixj} = \int (r^2 - x_i^2) \ \mathrm{d}m$ for $i = j$

where $r^2 = \sum_{i=1}^{3} x_i^2$ and x_i and x_j are Cartesian coordinates.

2 If the point is the centre of mass of the body, the axes and moments are called **central principal axes** and **central principal moments of inertia.**

3 In balancing, the term "principal inertia axis" is used to designate the one central principal axis (of the three such axes) most nearly coincident with the shaft axis of the rotor and is sometimes referred to as the "balance axis" or the "mass axis".

1.33 stiffness, k : The ratio of change of force (or torque) to the corresponding change in translational (or rotational) displacement of an elastic element.

1.34 compliance : The reciprocal of stiffness.

1.35 neutral surface (of a beam in simple flexure): That surface in which there is no longitudinal stress.

NOTE — It should be stated whether or not the neutral surface is a result of the flexure alone, or whether it is a result of the flexure and other superimposed loads.

1.36 neutral axis (of a beam in simple flexure) : The trace of the neutral surface on any cross-section of the beam.

1.37 transfer function (of a system) : A mathematical relation between the output (or response) and the input (or excitation) of the system.

NOTE — It is usually given as a function of frequency, and is usually a complex function. [See *response* (1.17), *transmissibility* (1.18), *transfer impedance* (1.44) and *frequency response* (B.13).]

1.38 complex excitation : An excitation having real and imaginary parts.

NOTES

1 The concepts of complex excitations and responses were evolved historically in order to simplify calculations. The actual excitation and response are the real parts of the complex excitation and response. If the system is linear, the concept is valid because superposition holds in such a situation.

2 This term should not be confused with excitation by a **complex vibration**, or vibration of **complex waveform.** The use of the term "complex vibration" in this sense is deprecated.

1.39 complex response : The response of a linear system to a complex excitation. [See the notes under *complex excitation* (1.38).]

1.40 complex system parameter : A complex quantity that is, or is derived from, the ratio of complex excitation to complex response.

NOTE — Electrical and mechanical impedances are examples of complex system parameters.

1.41 impedance : The ratio of a harmonic excitation of a system to its response (in consistent units), both of which are complex quantities and both of whose arguments increase linearly with time at the same rate. The term generally applies only to linear systems. [See *mechanical impedance* (1.42).]

NOTES

1 The concept is extended to non-linear systems where the term **incremental impedance** is used to describe a similar quantity.

2 The terms and definitions relating to impedance apply to systems undergoing sinusoidal vibrations only.

1.42 mechanical impedance : At a point in a mechanical system, the complex ratio of force to velocity where the force and velocity may be taken at the same or different points in the same system during simple harmonic motion.

NOTE — For the case of torsional mechanical impedance, the words "force" and "velocity" should be replaced by "torque" and "angular velocity".

1.43 direct impedance; driving-point impedance : In a mechanical sense, the complex ratio of the force to velocity taken at the same point in a mechanical system during simple harmonic motion. [See the notes under *impedance* (1.41) and *mechanical impedance* (1.42).]

1.44 transfer impedance : In a mechanical sense, the complex ratio of the force taken at one point in a mechanical system to the velocity taken at another point in the same system during simple harmonic motions. [See the notes under *impedance* (1.41) and *mechanical impedance* (1.42).]

1.45 free impedance : The ratio of the applied excitation force phasor to the resulting velocity phasor with all other connection points of the system free, i.e. having zero restraining forces. Free impedance is the arithmetic reciprocal of a single element of the mobility matrix.

NOTES

1 Histroically, often no distinction has been made between blocked impedance and free impedance. Caution should, therefore, be exercised in interpreting published data.

2 While experimentally determined free impedances could be assembled into a matrix, this matrix would be quite different from the blocked impedance matrix resulting from mathematical modelling of the structure and, therefore, would not conform to the requirements for using mechanical impedance in an overall theoretical analysis of the system.

1.46 loaded impedance : The loaded electrical impedance of a transducer, or the loaded driving-point mechanical impedance of a structure, is the impedance at the input when the output is connected to its normal load or structure.

1.47 blocked impedance, Z_{ij} : The blocked electrical impedance of a transducer, or the blocked driving-point mechanical impedance of a structure, is the impedance at the input when the output is connected to a load of infinite mechanical impedance.

NOTES

1 Blocked impedance is the frequency-response function formed by the ratio of the phasor of the blocking or driving-point force response at point i to the phasor of the applied excitation velocity at point j, with all other measurement points on the structure "blocked", i.e. constrained to have zero velocity. All forces and moments required to constrain fully all points of interest on the structure have to be measured in order to obtain a valied blocked impedance matrix.

2 Any changes in the number of measurement points or their location will change the blocked impedances at all measurement points.

3 The primary usefulness of blocked impedance is in the mathematical modelling of a structure using lumped mass, stiffness and damping elements or finite element techniques. When combining or comparing such mathematical models with experimental mobility data, it is necessary to convert the analytical blocked impedance matrix into a mobility matrix or *vice versa*.

1.48 frequency-response function : The frequency-dependent ratio of the motion-response phasor to the phasor of the excitation force.

NOTES

1 Frequency-response functions are properties of linear dynamic systems which do not depend on the type of excitation function. Excitation can be harmonic, random, or transient functions of time. The test results obtained with one type of excitation can thus be used for predicting the response of the system to any other type of excitation.

2 Lineartiy of the system is a condition which, in practice, will be met only approximately, depending on the type of system and on the magnitude of the input. Care has to be taken to avoid non-linear effects, particularly when applying impulse excitation. Structures which are known to be non-linear (for example certain riveted structures) should not be tested with impulse excitation and great care is required when using random excitation for testing such structures.

3 Motion may be expressed in terms of either velocity, acceleration or displacement; the corresponding frequency-response function designations are *mobility, accelerance* and *dynamic compliance or impedance, effective mass* and *dynamic stiffness,* respectively (see table 1).

1.49 frequency range of interest : Span, in Hertz, from the lowest frequency to the highest frequency at which, say, mobility data are to be obtained in a given test series.

Table 1 — Equivalent definitions to be used for various kinds of measured output/input ratio

	Motion expressed as displacement	**Motion expressed as velocity**	**Motion expressed as acceleration**
Term	Dynamic compliance[1]	Mobility[2]	Accelerance[3]
Symbol	x_i/F_j	$Y_{ij}=v_i/F_j$	a_i/F_j
Unit	m/N	m/(N.s)	m/(N.s^2) = kg^{-1}
Boundary conditions	$F_k=0$; $k \neq j$	$F_k=0$; $k \neq j$	$F_k=0$; $k \neq j$
See figure	3	1	2
Comment	Boundary conditions are easy to achieve experimentally.		
Term	Dynamic stiffness	Blocked impedance	Blocked effective mass
Symbol	F_i/x_j	$Z_{ij}=F_i/v_j$	F_i/a_j
Unit	N/m	(N.s)/m	(N.s^2)/m = kg
Boundary conditions	$x_k=0$; $k \neq j$	$v_k=0$; $k \neq j$	$a_k=0$; $k \neq j$
Comment	Boundary conditions are very difficult or impossible to achieve experimentally.		
Term	Free dynamic stiffness	Free impedance	Effective mass (free effective mass)
Symbol	F_j/x_i	$F_j/v_i=\frac{1}{Y_{ij}}$	F_j/a_i
Unit	N/m	(N.s)/m	(N.s^2)/m = kg
Boundary conditions	$F_k=0$; $k \neq j$	$F_k=0$; $k \neq j$	$F_k=0$; $k \neq j$
Comment	Boundary conditions are easy to achieve, but results shall be used with great caution in system modelling.		

1) "Dynamic compliance" is called "receptance" by several authors.

2) "Mobility" is sometimes called "mechanical admittance". A typical plot is given in figure 1.

3) "Accelerance" has unfortunately been called "inertance" in some publications. Inertance is not a standard term and is not acceptable because it is in conflict with the common definition of acoustic inertance and also contrary to the implication carried by the word "inertance".

1.50 (mechanical) mobility, Y_{ij}: The complex ratio of the velocity, taken at a point in a mechanical system, to the force, taken at the same or another point in the system, during simple harmonic motion.

NOTES

1 Mechanical mobility is the inverse of mechanical impedance.

2 Mobility is the frequency-response function formed by the ratio of the velocity-response phasor at point i to the excitation force phasor at point j with all other measurement points on the structure allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application. A typical plot is given in figure 1.

3 The velocity response can be either translational or rotational, and the excitation force can be either a rectilinear force or a moment.

4 If the velocity response measured is a translational one and if the excitation force applied is a rectilinear one, the units of the mobility term will be m/(N.s) in the SI system.

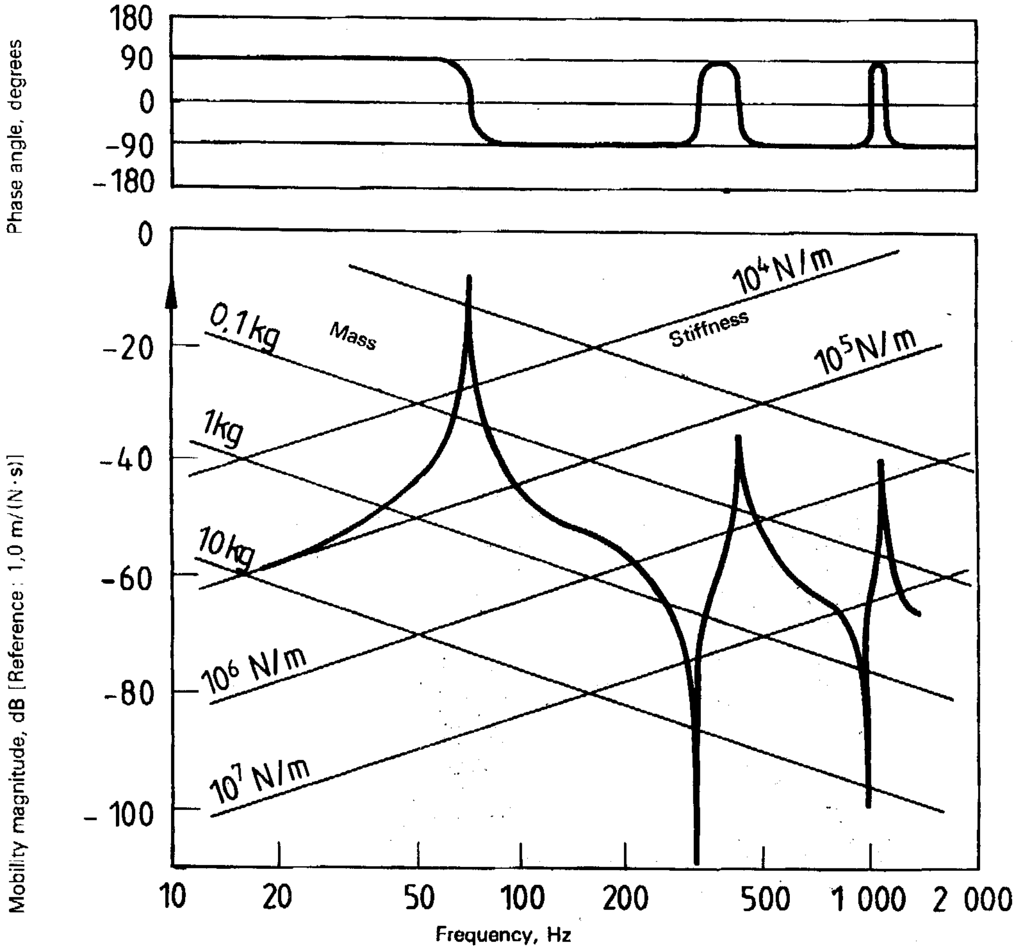

Figure 1 — Mobility plot

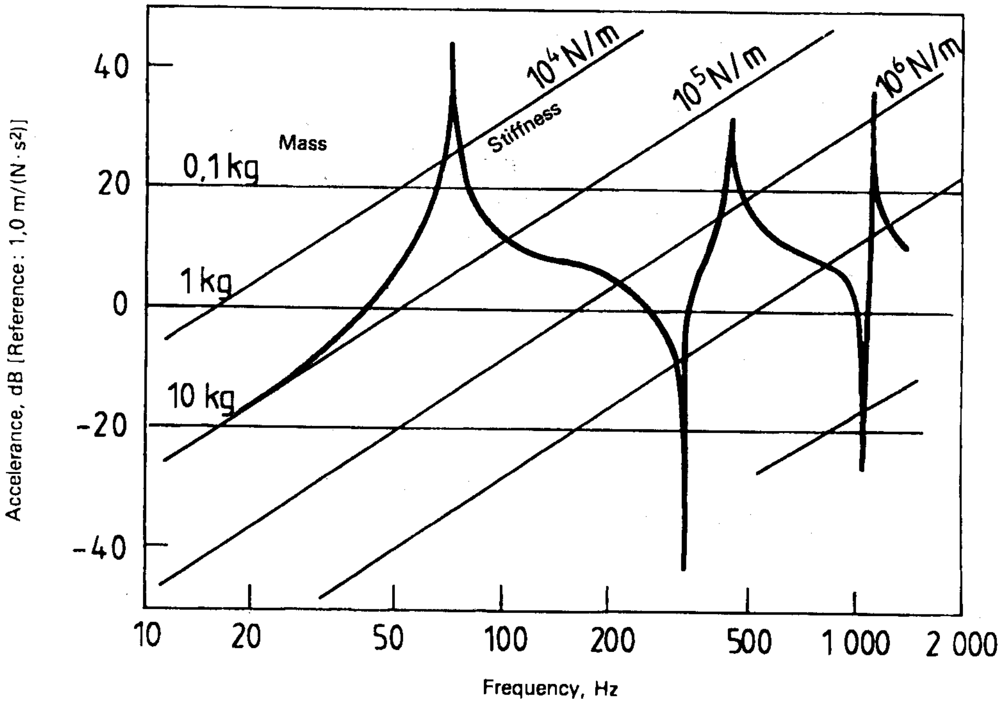

Figure 2 — Accelerance magnitude plot corresponding to the mobility graph plotted in figure 1

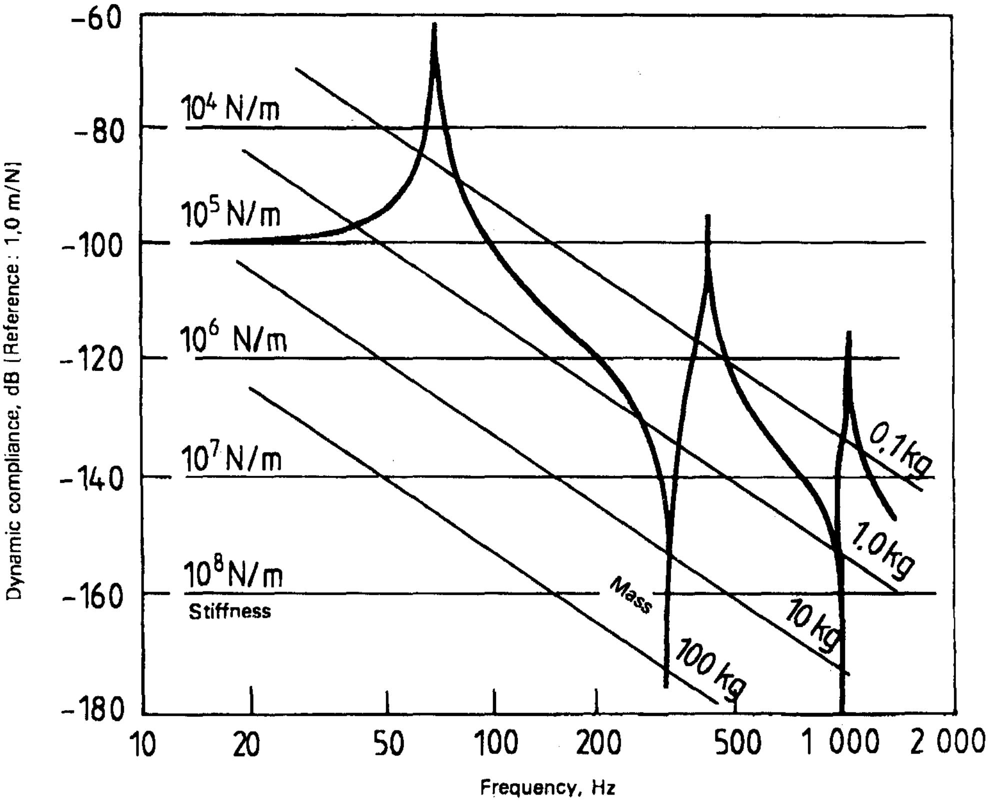

Figure 3 — Dynamic compliance magnitude plot corresponding to the mobility graph plotted in figure 1

1.51 direct (mechanical) mobility; driving-point (mechanical) mobility, Y_{jj} : The complex ratio of velocity and force taken at the same point in a mechanical system during simple harmonic motion.

NOTES

1 Driving-point mobility is the frequency-response function formed by the ratio, in metres per newton second, of the velocity-response phasor at point j to the excitation force phasor applied at the same point with all other measurement points on the structure allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

2 The term "point" designates a location and a direction. The term "coordinate" has also been used with the same meaning as "point".

1.52 frequency-averaged mobility magnitude : The r.m.s. value of the ratio, in metres per newton second, of the magnitude of the velocity response at point i to the magnitude of the exciting force at the same point, averaged over specified frequency bands.

1.53 transfer (mechanical) mobility : The complex ratio of the velocity, taken at one point in a mechanical system, to the force, taken at another point in the same system, during simple harmonic motion.

NOTE — Transfer mobility is the frequency-response function formed by the ratio, in metres per newton second, of the velocity-response phasor at point i to the excitation force phasor applied at point j with all points other than j allowed to respond freely without any constraints other than those constraints which represent the normal support of the structure in its intended application.

1.54 dynamic stiffness; dynamic elastic constant; dynamic spring constant, k_*:

(1) The ratio of change of force to change of displacement under dynamic conditions.

(2) The complex ratio of force to displacement during simple harmonic motion.

NOTES

1 The dynamic stiffness may be dependent upon strain (amplitude and/or spectrum), strain-rate, temperature or other conditions.

2 The dynamic stiffness, k_*, of a linear translational single-degree-of-freedom system characterized by the equation.

$$m \frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F$$

where $F = F_0 e^{i\omega t}$, is equal to

$$k_* = \frac{F_0}{x_0} = k - m\omega_0^2 + i\omega_0 c$$

In these equations,

m is the mass;

x is the displacement;

t is the time;

c is the linear (viscous) damping coefficient;

k is the elastic (spring) constant;

F_0 is the force amplitude;

e is the base of natural logarithms;

$i = \sqrt{-1}$;

ω is the angular frequency;

ω_0 is the undamped natural frequency;

x_0 is the displacement amplitude.

1.55 apparent mass; effective mass : The complex ratio of force to acceleration during simple harmonic motion.

NOTE — The ratio of force to acceleration, when the acceleration is given in terms of g, is sometimes called **effective weight** or **effective load.**

1.56 spectrum : A description of a quantity as a function of frequency or wavelength.

NOTE — The term "specturm" may be used to signify a continuous range of components, usually wide in extent, which have some common characteristics, for example audio-frequency spectrum.

1.57 level (of a quantity) : the logarithm of the ratio of the quantity to a reference of the same kind. The base of the logarithm, the reference quantity and the kind of level shall be specified.

NOTES

1 Examples of kinds of levels in common use are electric-power level, sound-pressure level, voltage-squared level.

2 The level as defined in this International Standard is measured in units of the logarithm of a reference ratio that is equal to the base of the logarithms.

3 The definition is expressed symbolically as

$$L = \log_r \left(\frac{q}{q_0}\right)$$

where

L is the level of the kind determined by the kind of quantity under consideration, measured in units of $\log_r r$;

r is the base of the logarithms and the reference ratio;

q is the quantity under consideration;

q_0 is the reference quantity of the same kind.

4 A difference in the levels of two like quantities q_1 and q_2 is described by the same formula because, by the rules of logarithms, the reference quantity is automatically divided out as follows :

$$\log_r \left(\frac{q_1}{q_0}\right) - \log_r \left(\frac{q_2}{q_0}\right) = \log_r \left(\frac{q_1}{q_2}\right)$$

5 In vibration terminology, the term "level" may sometimes be used to denote amplitude, average value, root-mean-square value, or ratios of these values. These uses are deprecated.

1.58 bel : A unit of level when the base of the logarithm is 10. Use of the bel is restricted to levels of quantities proportional to power. [See the notes under *level* (1.57) and *decibel* (1.59).]

1.59 decibel (dB) : One tenth of a bel.

NOTES

1 The magnitude of a level in decibels is ten times the logarithm to the base 10 of the ratio of power-like quantities, i.e.

$$L_p = 10 \log_{10} \left(\frac{X^2}{X_0^2}\right) = 20 \log_{10} \left(\frac{X}{X_0}\right)$$

2 Examples of quantities that qualify as power-like quantities are sound-pressure squared, particle-velocity squared, sound intensity, sound-energy density, voltage squared. Thus the bel is a unit of sound-pressure-squared level; it is common practice, however, to shorten this to sound-pressure level because ordinarily no ambiguity results from so doing.

2 Vibration

2.1 vibration : The variation with time of the magnitude of a quantity which is descriptive of the motion or position of a mechanical system, when the magnitude is alternately greater and smaller than some average value or reference. [See *oscillation* (1.8).]

2.2 periodic vibration : A periodic quantity the values of which recur for certain equal increments of the independent variable.

NOTES

1 A **periodic quantity,** y, which is a function of time, t, can be expressed as

$$y = f(t) = f(t \pm n\tau)$$

where

n is a whole number;

τ is a constant;

t is an independent variable.

2 A **quasi-periodic vibration** is a vibration which deviates only slightly from a periodic vibration.

2.3 simple harmonic vibration; sinusoidal vibration : A periodic vibration that is a sinusoidal function of the independent variable. Thus

$$y = A \sin (\omega t + \Phi)$$

where

y is the simple harmonic vibration;

A is the amplitude;

ω is the angular frequency;

t is the independent variable;

Φ is the phase angle of the vibration.

NOTES

1 The maximum value of the simple harmonic vibration is the amplitude A.

2 A periodic vibration consisting of the sum of more than one sinusoid, each having a frequency which is a multiple of the fundamental frequency, is often referred to as a **complex vibration** or **multi-sinusoidal vibration.** The use of the term "complex vibration" in this context is deprecated.

3 A **quasi-sinusoidal vibration** has the appearance of the sinusoid, but varies relatively slowly in frequency and/or in amplitude.

2.4 random vibration : A vibration the magnitude of which cannot be precisely predicted for any given instant of time. [See *random noise* (2.7).]

NOTE — The probability that the magnitude of a random vibration is within a given range can be specified by a probability distribution function.

2.5 non-stationary vibration : A random vibration that is not stationary.

2.6 noise :

(1) Any disagreeable or undesired sound.

(2) Sound, generally of a random nature, the spectrum of which does not exhibit clearly defined frequency components.

NOTE — By extension of the above definitions, noise may consist of electrical oscillations of an undesired or random nature. If ambiguity exists as to the nature of the noise, a term such as **acoustic noise** or **electrical noise** should be used.

2.7 random noise : A noise the magnitude of which cannot be precisely predicted for any given instant of time. [See *random vibration* (2.4) and the accompanying note.]

2.8 Gaussian random noise : A random noise whose instantaneous magnitudes have a Gaussian distribution. [See *Gaussian distribution* (A.32).]

2.9 white noise; white random vibration : White noise has equal energy for any frequency band of constant width (or per unit bandwidth) over the spectrum of interest.

NOTE — White random vibration has a constant mean-square acceleration spectral density over the frequency spectrum of interest. [See *power spectral density* (5.1).]

2.10 pink noise; pink random vibration : A noise which has a constant energy within a bandwidth proportional to the centre frequency of the band.

NOTE — The energy spectrum of pink noise as determined by an octave bandwidth (or any fractional part of an octave bandwidth) filter will have a constant value.

2.11 narrow-band random vibration : Random vibration having its frequency components within a narrow band only [See *random vibration* (2.4).]

NOTES

1 The defining of what is meant by "narrow" is a relative matter depending upon the problem involved. It is usually equal to or less than 1/3 octave.

2 The waveform of a narrow-band random vibration has the appearance of a sine wave the amplitude and phase of which vary in an unpredictable manner.

2.12 broad-band random vibration : Random vibration having its frequency components distributed over a broad frequency band. [See *random vibration* (2.4).]

NOTE — The definition of what is meant by "broad" is a relative matter depending upon the problem involved. It is usually one octave or greater.

2.13 dominant frequency : A frequency at which a maximum value occurs is a spectral density curve.

2.14 steady-state vibration : A steady-state vibration exists if the vibration is a continuing periodic vibration.

2.15 transient vibration : The vibratory motion of a system other than steady-state or random.

NOTE — This term is basically associated with *mechanical shock* (3.1).

2.16 forced vibration [oscillation] : The steady-state vibration [oscillation] caused by a steady-state excitation.

NOTES

1 The vibration (for linear systems) has the same frequencies as the excitation.

2 Transient vibrations [oscillations] are not considered.

2.17 free vibration; free oscillation : Vibration that occurs after the removal of excitation or restraint.

NOTE — The system vibrates at natural frequencies of the system.

2.18 self-induced vibration; self-excited vibration : Vibration of a mechanical system resulting from conversion, within the system, of non-oscillatory energy to oscillatory excitation.

2.19 ambient vibration : The all-encompassing vibration associated with a given environment, being usually a composite of vibration from many sources near and far.

2.20 extraneous vibration : The total vibration other than the vibration of principal interest.

NOTE — Ambient vibration contributes to the magnitude of extraneous vibration.

2.21 aperiodic motion : A vibration that is not periodic.

2.22 cycle (noun) : The complete range of states or values through which a periodic phenomenon or function passes before repeating itself identically. [See *cycle* (verb) (2.101).]

2.23 fundamental period; period : The smallest increment of the independent variable of a periodic quantity for which the function repeats itself. [See *periodic vibration* (2.2).]

NOTE — If no ambiguity is likely, the fundamental period is called the period.

2.24 (cyclic) frequency : The reciprocal of the fundamental period.

NOTE — The unit of frequency is the **hertz** (Hz), which corresponds to one cycle per second.

2.25 fundamental frequency :

(1) Of a periodic quantity, the reciprocal of the fundamental period.

(2) Of an oscillating system, the lowest natural frequency. The normal mode of vibration associated with this frequency is known as the fundamental mode.

2.26 harmonic (of a periodic quantity) : A sinusoid the frequency of which is an integral multiple of the fundamental frequency.

NOTES

1 The term **overtone** has frequently been used in place of harmonic, the n^{th} harmonic being called the $(n-1)^{th}$ overtone.

2 In English, the first overtone and the second harmonic are each twice the frequency of the fundamental. In French, the distinction between harmonic and overtone does not exist, and the second harmonic is twice the frequency of the fundamental. The term "overtone" is now deprecated to reduce ambiguity in the numbering of the components of a periodic quantity.

2.27 subharmonic : A sinusoidal quantity the period of which is an integral submultiple of the fundamental period of the quantity to which it is related.

2.28 beats : Periodic variations in the amplitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies. The beats occur at the difference frequency.

2.29 beat frequency : The absolute value of the difference in frequency of two oscillations of slightly different frequencies.

2.30 angular frequency; circular frequency : The product of the frequency of a sinusoidal quantity and the factor 2π.

NOTE — The unit of angular frequency is the radian per unit of time.

2.31 phase angle; phase (of a sinusoidal vibration) : The fractional part of a period through which a sinusoidal vibration has advanced as measured from a value of the independent variable as a reference.

2.32 phase difference; phase angle difference : Between two periodic vibrations of the same frequency, the difference between their respective phases or, in the case of sinusoidal vibrations, between their phase angles measured from the same origin.

2.33 amplitude : The maximum value of a sinusoidal vibration.

NOTES

1 This is sometimes called **vector amplitude** to distinguish it from other senses of the term "amplitude", and it is sometimes called **single amplitude,** or **peak amplitude,** to distinguish it from **double amplitude,** which for a simple harmonic vibration is the same as the total excursion (a displacement concept) or peak-to-peak value. The use of the terms "double amplitude" and "single amplitude" is deprecated.

2 In the vibration theory, the use of "amplitude", for purposes other than to describe the maximum value of a sinusoid, is deprecated.

2.34 peak value; peak magnitude; positive (negative) peak value : The maximum value of a vibration during a given interval. [See also *maximum value* (2.40).]

NOTE — A peak value vibration is usually taken as the maximum deviation of that vibration from the mean value. A positive peak value is the maximum positive deviation and a negative peak value is the maximum negative deviation.

2.35 peak-to-peak value (of a vibration) : The algebraic difference between the extreme values of the vibration.

2.36 excursion; total excursion (of a vibration) : The peak-to-peak displacement.

2.37 crest factor (of a vibration); **peak-to-r.m.s. ratio** : The ratio of the peak value to the r.m.s. value.

NOTE — The value of the crest factor of a sine wave is $\sqrt{2}$.

2.38 form factor (of a vibration) : The ratio of the r.m.s. value to the mean value for one-half cycle between two successive zero crossings.

NOTE — The form factor for a sinusoid is $\pi/2\ \sqrt{2} = 1,111$.

2.39 instantaneous value; value : The value of a variable quantity at a given instant.

2.40 maximum value : The value of a function when any small change in the independent variable causes a decrease in the value of the function.

2.41 maximax : The maximum value that is of greatest magnitude when a function contains more than one maximum value within a given interval of the independent variable.

2.42 vibration severity : A generic term that designates a value, or set of values, such as a maximum value, average or r.m.s. value, or other parameter that is descriptive of the vibration. It may refer to instantaneous values or to average values.

NOTES

1 The vibration severity of a machine is defined by the maximum r.m.s. value of the vibration velocities measured at significant points of a machine, such as bearings or mountings.

2 The duration of a vibration is sometimes included as a parameter descriptive of vibration severity. This usage is deprecated.

2.43 elliptical vibration : A vibration in which the locus of a vibrating point is elliptical in form.

2.44 rectilinear vibration; linear vibration : A vibration in which the locus of a vibration point is a straight line.

2.45 circular vibration : A vibration in which the locus of a vibrating point is circular in form. This is a special case of elliptical vibration.

2.46 node : A point, line or surface in a standing wave where some characteristic of the wave field has essentially zero amplitude.

NOTE — If the nature of the node is not apparent, an appropriate modifier should be used, for example displacement node, pressure node, etc.

2.47 antinode; loop : A point, line or surface in a standing wave where some characteristic of the wave field has a maximum value.

NOTE — If the nature of the antinode is not apparent, an appropriate modifier should be used, for example displacement antinode, pressure, antinode, etc.

2.48 mode of vibration : In a system undergoing vibration, a mode of vibration designates the characteristic pattern of nodes and antinodes assumed by the system in which the motion of every particle, for a particular frequency, is simple harmonic (for linear systems) or has corresponding decay patterns.

NOTE — Two or more modes may exist concurrently in a multi-degree-of-freedom system.

2.49 natural mode of vibration : A mode of vibration assumed by a system when vibrating freely.

NOTES

1 If the system has zero damping, the natural modes are the same as the normal modes. [see *normal mode* (2.55).]

2 A natural mode of vibration exists for each degree of freedom of the system.

2.50 fundamental natural mode of vibration : The mode of vibration of a system having the lowest natural frequency. [see *fundamental frequency* (2.25).]

2.51 mode shape : The mode shape of a given mode of vibration of a mechanical system is given by the maximum change in position, usually normalized to a specified deflection magnitude at a specified point, of its neutral surface (or neutral axis) from its mean value. The mean value is the mean for the given mode of vibration only.

2.52 modal numbers : When the normal modes of a system are identified by sets of integers, these integers are called modal numbers.

2.53 coupled modes : Modes of vibration that are not independent but which influence one another because of energy transfer from one mode to another.

2.54 uncoupled modes : Modes of vibration that can exist in a system concurrently with and independently of other modes, no energy being transferred from one mode to another.

2.55 normal mode : A natural mode of an undamped mechanical system.

NOTES

1 The motion of a system consists of the summation of the contribution of each of the participating normal modes.

2 The terms **natural mode, characteristic mode** and **eigen mode** are synonymous with normal mode for undamped systems.

2.56 wave : A modification of the physical state of a medium, which is propagated through the medium by virtue of the physical characteristics of the medium.

NOTE — At any point in the medium the quantity serving as a measure of the disturbances is a function of time and at any instant the quantity is a function of position.

2.57 wave train : A succession of a limited number of waves, usually nearly periodic, travelling at the same (or nearly the same) velocity.

2.58 wavelength (of a periodic wave) : The distance measured perpendicular to the wave front in the direction of propagation, between two successive points on the wave, which are separated by one period.

2.59 compressional wave : A wave of compressive or tensile stresses propagated in an elastic medium.

NOTE — A compressional wave is normally a longitudinal wave. [See *longitudinal wave* (2.60).]

2.60 longitudinal wave : A wave in which the direction of displacement caused by the wave motion is parallel to the direction of propagation.

2.61 shear wave : A wave of shear stresses propagated in an elastic medium.

NOTES

1 A shear wave is normally a transverse wave. [See *transverse wave* (2.62).]

2 A shear wave causes no changes in volume.

2.62 transverse wave : A wave of displacement of elements of the medium propagated perpendicular to the wave front.

2.63 wave front :

(1) Of a progressive wave in space, the continuous surface which is a locus of points where the phase is the same at a given instant.

(2) Of a progressive surface wave, the continuous line which is a locus of points where the phase is the same at a given instant.

2.64 plane wave : A wave in which the wave fronts are parallel planes.

2.65 spherical wave : A wave in which the wave fronts are concentric spheres.

2.66 standing wave : A periodic wave having a fixed amplitude distribution in space, i.e. the result of interference of progressive waves of the same frequency and kind.

NOTES

1 A standing wave can be considered to be the result of superposition of opposing progressive waves of the same frequency and kind.

2 Standing waves are characterized by nodes and antinodes that are fixed in position.

2.67 audio frequency : Any frequency of a normally audible sound wave.

NOTE — Audio frequencies generally lie between 20 Hz and 20 000 Hz.

2.68 ultrasonic frequency; ultrasonic : a frequency lying above the audio frequency range.

NOTE — The term "ultrasonic" may be used as a modifier to indicate a device intended to operate in association with ultrasonic vibrations.

2.69 infrasonic frequency; infrasonic : A frequency lying below the audio frequency range.

NOTE — The term "infrasonic" may be used as a modifier to indicate a device intended to operate in association with infrasonic vibrations.

2.70 reverberation : The sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source of the sound has stopped.

2.71 echo : A wave that has been reflected or returned with sufficient magnitude and delay to be detected as a wave distinct from that directly transmitted and distinguishable as a repetition of it.

2.72 resonance : Resonance of a system in forced oscillation exists when any change, however small, in the frequency of excitation causes a decrease in a response of the system.

2.73 resonance frequency : A frequency at which resonance exists.

NOTES

1 Resonance frequencies may depend upon the measured variables, for example velocity resonance may occur at a different frequency from that of displacement resonance. (See table 2.)

2 In case of possible confusion, the type of resonance shall be indicated, for example velocity resonance frequency. (See table 2).

2.74 antiresonance : Antiresonance of a system in forced oscillation exists at a point when any

Table 2 — Resonance relations

Characteristic	Displacement resonance	Velocity resonance	Damped natural frequency
Frequency, H_z	$\frac{1}{2\pi}\sqrt{\frac{k}{m}-\frac{c^2}{2m^2}}$	$\frac{1}{2\pi}\sqrt{\frac{k}{m}}$	$\frac{1}{2\pi}\sqrt{\frac{k}{m}-\frac{c^2}{4m^2}}$
Amplitude of displacement	$\frac{A}{c\sqrt{\frac{k}{m}-\frac{c^2}{4m^2}}}$	$\frac{A}{c\sqrt{\frac{k}{m}}}$	$\frac{A}{c\sqrt{\frac{k}{m}-\frac{3c^2}{16m^2}}}$
Amplitude of velocity	$\frac{A}{c\sqrt{1+\frac{c^2}{4mk-2c^2}}}$	$\frac{A}{c}$	$\frac{A}{c\sqrt{1+\frac{c^2}{16mk-4c^2}}}$
Phase of displacement with reference to applied force	$\tan^{-1}\sqrt{\frac{4mk}{c^2}-2}$	$\frac{\pi}{2}$	$\tan^{-1}\sqrt{\frac{16mk}{c^2}-4}$

NOTES

1 In the case of a linear single degree-of-freedom system, the motion of which can be described by the equation

$$m\frac{d^2x}{dt^2}+c+\frac{dx}{dt}+kx=A\,\mathrm{Cos}\,\omega t$$

where

x is a displacement;

ω is the angular frequency;

m, c and k are constants;

the characteristics of the different kinds of resonance in terms of the constants of the above equation are as given in the table.

2 For values of c which are small compared with $\sqrt{mk}$ there is little difference between the three cases. The frequency at velocity resonance is equal to the undamped natural frequency of the system. Other symbols are employed for electrical resonance.

change, however small, in the frequency of excitation causes an increase in a response at this point.

2.75 antiresonance frequency : A frequency at which antiresonance occurs.

NOTES

1 Antiresonance frequencies may depend upon the measured variable, for example velocity antiresonance may occur at a different frequency from that of displacement antiresonance.

2 In cases of possible confusion, the type of antiresonance shall be indicated, for example velocity antiresonance frequency.

2.76 fixed-base natural frequency : A natural frequency that a system would have if the foundation to which the equipment is attached were rigid and of infinite mass.

NOTE — The equation given in table 2 and the natural frequencies shown are for fixed-base conditions.

2.77 critical speed : A characteristic speed at which resonances of a system are excited.

NOTES

1 Critical speed of a rotating system is a speed of the rotating system that corresponds to a resonance frequency (it may also include multiples and submultiples of the resonance frequency) of the system, for example speed in revolutions per unit time equals the resonance frequency in cycles per unit time.

2 Where there are several rotating systems, there will be several corresponding sets of critical speeds, one for each mode of the overall system.

2.78 subharmonic response; subharmonic resonance response : A response of a mechanical system exhibiting some of the characteristics of resonance at a frequency having a period which is an integral multiple of the period of excitation.

2.79 damping : The dissipation of energy with time or distance.

NOTE — In the context of vibration and shock, damping is the progressive reduction of the amplitude with time.

2.80 undamped natural frequency (of a mechanical system) : A frequency of free vibration resulting from only elastic and inertial forces of the system.

NOTE — For the equation of motion given in table 2, the undamped natural frequency is $(1/2\pi)\sqrt{k/m}$ Hz.

2.81 damped natural frequency : The frequency of free vibration of a damped linear system. (See table 2.)

2.82 viscous damping; linear viscous damping : The dissipation of energy that occurs when an element or a part of a vibration system is resisted by a force the magnitude of which is proportional to the velocity of the element and the direction of which is opposite to the direction of the velocity.

2.83 equivalent viscous damping : A value of linear viscous damping, assumed for the purpose of analysis of a vibratory motion, such that the dissipation of energy per cycle at resonance is the same for the assumed as well as for the actual damping force.

2.84 linear viscous damping coefficient; viscous damping coefficient : For linear viscous damping, the ratio of damping force to velocity. [See *linear viscous damping* (2.82).]

2.85 critical damping; critical viscous damping : For a single degree-of-freedom system, the amount of viscous damping which corresponds to the limiting condition between an oscillatory and a non-oscillatory transient state of free vibration.

NOTE — The critical linear viscous damping coefficient, c_c, is equal to

$$c_c = 2\sqrt{mk} = 2m\omega_0$$

for the single degree-of-freedom system represented by the equation given in table 2, where ω_0 is the undamped natural frequency (angular). [See *undamped natural frequency* (2.80).]

2.86 damping ratio; fraction of critical damping : For a system with linear viscous damping, the ratio of the actual damping coefficient to the critical damping coefficient. [See *linear viscous damping coefficient* (2.84) and *critical damping* (2.85).]

NOTE — The fraction of critical damping may also be expressed in terms of percent of critical damping.

2.87 logarithmic decrement : The natural logarithm of the ratio of any two successive amplitudes of like sign in the decay of a single-frequency oscillation.

2.88 non-linear damping : Phenomenon associated with the energy loss of a system whereby the motion of the system cannot be characterized by a linear differential, integral or integro-differential equation with constant coefficients.

2.89 Q; Q factor : A quantity which is a measure of the sharpness of resonance, or frequency selectivity, of a resonant oscillatory system having a single degree of freedom, either mechanical or electrical.

NOTE — The quantity Q is equal to one-half the reciprocal of the damping ratio:

$$Q = \frac{1}{2\,c/c_c}$$

2.90 vibration generator; vibration machine : A machine that is specifically designed for and is capable of generating vibrations and of imparting these vibrations to other structures or devices.

NOTE — Equipment to be tested may be attached to a table on the generator or the generator may be used to excite equipment by means of studs without the use of a table.

2.91 vibration generator system : The vibration generator and associated equipment necessary for its operation.

2.92 electrodynamic vibration generator; electrodynamic vibration machine : A vibration generator which derives its vibratory force from the interaction of a magnetic field of constant value, and a coil of wire contained in it which is excited by a suitable alternating current.

NOTE — The **moving element** of an electrodynamic vibration generator includes the vibration table, the moving coil, and all the parts of the generator that are intended to participate in the vibration.

2.93 electromagnetic vibration generator : A vibration generator which derives its vibratory force from the interaction of electromagnets and magnetic materials.

2.94 mechanical direct-drive vibration generator; direct-drive vibration generator : A vibration machine in which the vibration table is forced, by a positive linkage, to undergo a displacement amplitude of vibration that remains essentially constant regardless of the load or frequency of operation.

2.95 hydraulic vibration generator : A vibration generator which derives its vibratory force from the application of a liquid pressure through a suitable drive arrangement.

2.96 mechanical reaction type vibration generator; unbalanced mass vibration generator : A vibration machine in which the forces exciting the vibration are generated by rotating or reciprocating unbalanced masses.

2.97 resonance vibration generator : A vibration generator which contains a vibration system which is excited at its resonance frequency.

2.98 piezoelectric vibration generator : A vibration generator which has a piezoelectric transducer as its force-generating element.

2.99 magnetostrictive vibration generator : A vibration generator which has a magnetostrictive transducer as its force-generating element.

2.100 deadweight; pure mass; lumped mass : A mass having the characteristics of a perfectly rigid mass over the frequency region of concern.

2.101 cycle (verb) : A device is said to be cycled if it is operated repetitively through a range of a controlled variable such as frequency. [See *cycle* (noun) (2.22).]

2.102 cycle period : The time required to cycle a device through all the controlled variables in the control range.

2.103 cycle range : Cycle range is defined by the minimum and maximum values of the controlled variable, such as frequency, between which the device is cycled.

2.104 sweep (as applied to the operation of a vibration generator) : The process of traversing continuously through a range of values of an independent variable, usually frequency.

2.105 sweep rate : The rate of change of the independent variable, usually frequency, for example $\mathrm{d}f/\mathrm{d}t$ where f is frequency and t is time.

2.106 uniform sweep rate; linear sweep rate : A sweep rate for which the rate of change of the independent variable for a sweep, usually frequency, is constant, i.e. $\mathrm{d}f/\mathrm{d}t$ = constant. [See *sweep rate* (2.105).]

2.107 logarithmic frequency sweep rate : A sweep rate for which the rate of change of frequency per unit of frequency is constant, i.e. $(\mathrm{d}f/f)/\mathrm{d}t$ = constant. [See *sweep rate* (2.105).]

NOTES

1 For a logarithmic sweep rate, the time to sweep between any two frequencies of fixed ratio is constant.

2 It is recommended that logarithmic sweep rate be expressed in octaves per minute.

2.108 cross-over frequency (in vibration environmental testing) : That frequency at which a characteristic of a vibration changes from one relationship to another.

NOTE — For example, a cross-over frequency may be that frequency at which the vibration amplitude, or r.m.s. value, changes from a constant displacement value versus frequency to a constant acceleration value versus frequency.

2.109 isolator : A support, usually resilient, the function of which is to attenuate the transmission of shock and/or vibration.

NOTE — An isolator may include collapsible parts, servo-mechanisms or other devices in lieu of, or in addition to, the resilient member.

2.110 vibration isolator : An isolator designed to attenuate the transmission of vibration in a frequency range.

2.111 shock isolator : An isolator designed to protect a system from a range of shock motions or forces.

2.112 centre-of-gravity mounting system : A centre-of-gravity mounting system exists if, when the mounted equipment is displaced by translation from its neutral position, there is no resultant moment about any axis through the centre of mass.

NOTE — In an ideal case, if an equipment is supported by a centre-of-gravity mounting system, then all natural (rigid-body) modes of vibration of the equipment on its mounts are decoupled. Translational motions of excitation will not excite rotational modes of vibration and *vice versa*. In practice, this is very difficult to achieve.

2.113 shock absorber : A device for the dissipation of energy in order to reduce the response of a mechanical system to applied shock.

2.114 damper; absorber : In vibration applications, a device used for reducing the magnitude of a shock or vibration by energy dissipation methods.

2.115 snubber : A device used to restrict the relative displacement of a mechanical system by increasing the stiffness of an elastic element in the system (usually abruptly and by a large factor) whenever the displacement becomes larger than a specified amount.

2.116 dynamic vibration absorber : a device for reducing vibrations of a primary system over a desired frequency range by the transfer of energy to an auxiliary system in resonance so tuned that the force exerted by the auxiliary system is opposite in phase to the force acting on the primary system.

NOTE — Dynamic vibration absorbers may be damped or undamped, but damping is not the primary purpose.

2.117 detuner : An auxiliary vibratory system with an amplitude-dependent frequency characteristic which modifies the vibration characteristics of the main system to which it is attached.

NOTE — An example is an auxiliary mass controlled by a non-linear spring.

3 Mechanical shock

3.1 mechanical shock; shock : A sudden change of force, position, velocity or acceleration that excites transient disturbances in a system.

NOTE — The change is normally considered sudden if it takes place in a time that is short compared with the fundamental periods of concern.

3.2 shock pulse : A form of shock excitation characterized by a sudden rise and/or sudden decay of a time-dependent parameter (such as motion, force or velocity).

NOTE — A descriptive mechanical term should be used, for example acceleration shock pulse.

3.3 applied shock; shock excitation : An excitation, applied to a system, that produces a mechanical shock.

3.4 shock motion : A transient motion causing, or resulting from a shock excitation.

3.5 impact : A single collision of one mass with a second mass.

3.6 impulse :

(1) The integral with respect to time of a force taken over the time during which the force is applied.

(2) For a constant force, the product of the force and the time during which the force is applied.

NOTE — In shock usage, the time interval is relatively short.

3.7 bump : A form of shock which is repeated many times for test purposes.

3.8 ideal shock pulse : A shock pulse that is described by a simple time function, for example those defined in 3.9 to 3.15.

3.9 half-sine shock pulse : An ideal shock pulse for which the time-history curve has the shape of the positive (or negative) section of one cycle of a sine wave.

3.10 final peak sawtooth shock pulse; terminal peak sawtooth shock pulse : An ideal shock pulse for which the time-history curve has a triangular shape for which the motion increases linearly to a maximum value and then drops instantaneously to zero.

3.11 initial peak sawtooth shock pulse : An ideal shock pulse for which the motion rises instantaneously to a maximum value, after which it decreases linearly to zero.

3.12 symmetrical triangular shock pulse : An ideal shock pulse for which the time-history curve has the shape of an isosceles triangle.

3.13 versine shock pulse; haversine shock pulse : An ideal shock pulse for which the time-history curve has the shape of one full cycle of a versine curve beginning at zero (sine-squared curve).

3.14 rectangular shock pulse : An ideal shock pulse for which the motion rises instantaneously to a given value, remains constant for the duration of the pulse, then instantaneously drops to zero.

3.15 trapezoidal shock pulse : An ideal shock pulse for which the motion rises linearly to a given value, which then remains constant for a period of time after which it decreases to zero in a linear manner.

3.16 nominal shock pulse; nominal pulse : A specified shock pulse that is given with specified tolerances.

NOTES

1 "Nominal shock pulse" is a generic term. It requires an additional modifier to make its meaning specific, for example nominal half-sine shock pulse, or nominal sawtooth shock pulse.

2 The tolerances of the nominal pulse from the ideal may be expressed in terms of pulse shapes (including area), or corresponding spectra.

3.17 nominal value of a shock pulse : A specified value (for example peak value or duration) given with specified tolerances.

3.18 duration of shock pulse : The time-interval between the instant the motion rises above some stated fraction of the maximum value and the instant it decays to this fraction.

NOTES

1 This definition is limited to pulses of simple shape.

2 For measured pulses, the "stated fraction" is usually taken as 1/10. For ideal pulses, it is taken as zero.

3.19 rise time; pulse rise time : The interval of time required for the value of the pulse to rise from some specified small fraction of the maximum value to some specified large fraction of the maximum value.

NOTE — For measured pulses, the "specified small fraction" is usually taken as 1/10 and the "specified large fraction" as 9/10. For ideal pulses, the fractions are taken as 0 and 1,0.

3.20 pulse drop-off time; pulse decay time : The interval of time required for the value of the pulse to drop from some specified large fraction of the maximum value to some specified small fraction of the maximum value.

NOTE — See the note to 3.19.

3.21 blast; air blast; underwater blast : The pressure pulse and associated air or water motion resulting from an explosion or other sudden change of pressure in the atmosphere or water.

3.22 shock wave : A shock time history (displacement pressure or other variable) associated with the propagation of the shock through a medium or structure.

NOTE — In liquids and gases, a shock wave is usually characterized by a wave front in which the pressure rises suddenly to a relatively large value.

3.23 shock testing machine; shock machine : A device for subjecting a system to controlled and reproducible mechanical shock.

3.24 shock response spectrum :

(1) The description of the responses to an applied shock of a series of systems of a specified type as a function of their natural frequencies.

(2) As used in the field of mechanical shock, an expression that approximates the maximum responses (displacement, velocity or acceleration) to an applied shock of an assembly of linear single degree-of-freedom systems, as a function of their natural frequencies.

NOTES

1 "Shock response spectrum" is a generic term. It requires an additional modifier to make its measuring specific, for example acceleration or velocity or displacement shock response spectrum.

2 If the amount and type of damping of the systems are not given, they are assumed to be zero. Unless otherwise indicated, the responses are maximum absolute values irrespective of sign and the time at which the maximum occurs. This is often referred to as maximax shock response spectrum. If reference is made to other types of shock response spectra, this shall be stated.

3 It should be noted that the concept of a shock response specturm is not fully consistent with the definition of spectrum (see 1.56).

4 Transducers for shock and vibration measurement

4.1 transducer : A device designed to receive energy from one system and supply energy, of either the same or of a different kind, to another in such a manner that the desired characteristics of the input energy appear at the output.

4.2 electromechanical pick-up : A transducer which is actuated by energy from a mechanical system (strain, force, motion, etc), and supplies energy to an electrical system, or *vice versa.*

NOTE — The principal types of transducers used in vibration and shock are

a) piezoelectric accelerometer;

b) piezoresistive accelerometer;

c) strain-gauge type accelerometer;

d) variable-resistance transducer;

e) electrostatic (capacitor) (condenser) transducer;

f) bonded-wire (foil) strain-gauge;

g) variable-reluctance transducer;

h) magnetostriction transducer;

i) moving-conductor transducer;

j) moving-coil transducer;

k) induction transducer;

l) electronic transducer.

4.3 seismic pick-up : A transducer consisting of a seismic system in which the differential movement between the mass and the base of the system produces an electrical output.

NOTE — Acceleration pick-ups operate in a frequency range below the significant natural frequency of the seismic system. Velocity and displacement pick-ups operate in a frequency range above the natural frequency of the seismic system.

4.4 linear transducer : A transducer for which the output quantity and the input quantity are linearly related within a specified frequency and amplitude range.

4.5 unilateral transducer : A transducer that cannot be actuated by signals at its outputs in such a manner as to supply related signals at its inputs.

4.6 bilateral transducer : A transducer capable of transmission in either direction between its terminations.

NOTE — A bilateral transducer usually satisfies the principle of reciprocity.

4.7 sensing element : That part of a transducer that is activated by the input excitation and supplies the output signal.

4.8 rectilinear transducer : A transducer designed to be sensitive to some characteristic of a translational motion.

NOTE — The modifier "rectilinear" is used only when it is necessary to distinguish this type of transducer from those sensitive to rotational motions.

4.9 angular transducer : A transducer designed to measure some characteristic of rotational motion.

4.10 accelerometer; acceleration pick-up : A pick-up which converts an input acceleration to an output (usually electrical) that is proportional to the input acceleration.

4.11 velocity pick-up : A pick-up that converts an input velocity to an output (usually electrical) that is proportional to the input velocity.

4.12 displacement pick-up : A pick-up that converts an input displacement to an output (usually electrical) that is proportional to the input displacement.

4.13 vibrograph : An instrument, usually self-contained and mechanical in operation, that can present an oscillographic recording of a vibration waveform.

4.14 vibrometer : An instrument capable of indicating on a scale some measure of the magnitude of a vibration, such as peak velocity, r.m.s. acceleration, etc.

4.15 sensitivity (of a transducer) : The ratio of a specified output quantity to a specified input quantity.

NOTE — The sensitivity of a transducer is usually determined for sinusoidal excitation.

4.16 calibration factor (of a transducer) : The average sensitivity within a specified frequency range. [See *sensitivity* (4.15).]

4.17 sensitive axis (of a rectilinear transducer) : The nominal direction for which a rectilinear transducer has the greatest sensitivity.

4.18 transverse axis (of a transducer) : Any nominal direction perpendicular to the sensitive axis.

4.19 transverse sensitivity (of a rectilinear transducer); **cross-sensitivity** : The sensitivity of a transducer to excitation in a nominal direction perpendicular to its sensitive axis.

NOTE — The transverse sensitivity is usually a function of the nominal direction of the axis chosen.

4.20 transverse sensitivity ratio (of a rectilinear transducer); **cross-sensitivity ratio** : The ratio of the transverse sensitivity of a transducer to its sensitivity along its sensitive axis.

4.21 transducer phase shift : The phase angle between the transducer output and input for sinusoidal excitation.

4.22 transducer distortion : Distortion which occurs when the output of the transducer is not proportional of the input.

4.23 amplitude distortion (of a transducer) : Distortion occurring when the ratio of the output of a transducer to its input at a given frequency varies with the input amplitude.

4.24 frequency distortion; frequency response : Distortion or response occurring within a given frequency range when the amplitude sensitivity of the transducer for a given amplitude of excitation is not constant over that range.

4.25 phase distortion : Distortion occurring when the phase angle between the output of a transducer and its input is not a linear function of frequency.

5 Data processing

5.1 power spectral density; auto-spectral density; auto spectrum : The power spectral density G (*f*) of a quantity $\xi(t)$ is the mean-square value of that part of the quantity passed by a narrow-band filter of centre frequency *f*, per unit bandwidth, in the limit as the bandwidth approaches zero and the averaging time approaches infinity.

NOTES

1 Power spectral density can be expressed as

$$G(f) = \lim_{\substack{B \to 0 \\ T \to \infty}} \frac{1}{BT} \int_0^T \xi^2(f, t, B)\, \mathrm{d}t$$

where

$\xi^2(f, t, B)$ is the result of passing $\xi(t)$ through a narrow-band-pass filter of bandwidth B centred at f, and then squaring the output;

T is the averaging time.

in terms of Fourier transforms, $G(f)$ can be expressed as

$$G(f) = \lim_{T \to \infty} \frac{2}{T} \left| F(f, T) \right|^2$$

where

$$f \geq 0;$$

$$F(f, T) = \int_0^T \xi(t) \, e^{-i2\pi ft} \, dt$$

2 Power spectral density is a generic term used regardless of the physical process represented by the time-history. The physical process involved is indicated in referring to particular data.

For example, the term **acceleration power spectral density** or **acceleration spectral density** is used instead of power spectral density when the acceleration spectrum is to be described.

3 For stationary processes, the power spectral density is twice the Fourier transform [see *Fourier spectrum* (A.21)] of the autocorrelation function, and may be expressed as

$$\begin{aligned} G(f) &= 2 \int_{-\infty}^{\infty} R(t) \, e^{-i2\pi ft} \, dt \\ &= 4 \int_0^{\infty} R(t) \cos(2\pi ft) \, dt \ (f \geq 0) \end{aligned}$$

5.2 power spectrum : A spectrum of mean-squared spectral density values.

5.3 cross-spectral density; cross-spectrum : Complex valued function of frequency f, of two quantities $\xi_1(t)$ and $\xi_2(t)$ defined by

$$G_{1,2}(f) = C_{1,2}(f) - iQ_{1,2}(f)$$

where

the real part $C_{1,2}(f)$, called the coincident spectral density function (or co-spectrum), is the average product of $\xi_1(t)$ and $\xi_2(t)$ at frequency f per unit bandwidth, for an appropriate bandwidth B and averaging time T. The real part, $C_{1,2}(f)$, is thus given by the following equation :

$$C_{1,2}(f) = \lim_{\substack{B \to 0 \\ T \to \infty}} \frac{1}{BT} \int_0^T \xi_1(f, t, B) \, \xi_2(f, t, B) \, dt$$

where

$\xi_1(f, t, B)$ and $\xi_2(f, t, B)$ are the results of passing ξ_1 and $\xi_2(t)$, respectively, through identical narrow-band-pass filters of bandwidth B centred at f;

the imaginary part $Q_{1,2}(f)$, called the quadrature spectral density function (or quad-spectrum), is also an average product of $\xi_1(t)$ and $\xi_2(t)$ at frequency f per unit bandwidth, except that $\xi_2(t)$ is shifted in phase to produce a 90° phase lag. The imaginary part, $Q_{1,2}(f)$, is thus given by the following equation:

$$Q_{1,2}(f) = \lim_{\substack{B \to 0 \\ T \to \infty}} \frac{1}{BT} \int_0^T \xi_1(f, t, B) \, \xi_2^0(f, t, B) \, dt$$

where

$\xi_1(f, t, B)$ is the result of passing $\xi_1(t)$ through a narrow-band-pass filter of bandwidth B centred at f;

$\xi_2^0(f, t, B)$ denotes a 90° phase lag from $\xi_2(f, t, B)$ which is the result of passing $\xi_2(t)$ through a narrow-band-pass filter of bandwidth B centred at f.

NOTES

1 For the definitions of the function $G(f)$, see the notes under *power spectral density* (5.1).

2 The functions $C_{1,2}(f)$ and $Q_{1,2}(f)$ can ben expressed in terms of Fourier transforms as follows :

$$C_{1,2}(f) = \lim_{T \to \infty} \frac{2}{T} \ \mathrm{Re}\left[F_1^*(f, T) . F_2(f, T)\right]$$

$$Q_{1,2}(f) = \lim_{T \to \infty} \frac{2}{T} \ Im\left[F_1^*(f, T) . F_2(f, T)\right]$$

where

$$f \geq 0;$$

$$F_1^*(f, T) = \int_0^T \xi_1(t) e^{i2\pi ft} \, dt;$$

$$F_2(f, T) = \int_0^T \xi_2(t) e^{-i2\pi ft} \, dt;$$

Re [...] and Im [...] are the real and imaginary parts, respectively, of the function in the brackets.

3 In terms of finite Fourier transforms, $G_{1,2}(f)$ can be expressed as

$$G_{1,2}(f) = \lim_{T \to \infty} \frac{2}{T} \left[F_1^*(f, T) \, F_2(f_2 T)\right]$$

4 In terms of the Fourier transform of the cross-correlation function ($R_{1,2}$), $G_{1,2}(f)$ can be expressed as

$$G_{1,2}(f) = 2 \int_{-\infty}^{+\infty} R_{1,2}(t) \, e^{-i2\pi ft} \, dt$$

5.4 coherence function : The ratio of the square of the absolute value of the cross-spectral density function to the product of the spectral density functions of the two quantities $\xi_1(t)$ and $\xi_2(t)$.

The coherence function is given by the following expression :

$$\gamma_{1,2}^2(f) = \frac{|G_{1,2}(f)|^2}{G_1(f) . G_2(f)}$$

At any frequency f, the coherence function satisfies $0 \leq \gamma_{1,2}^2(f) \leq 1$.

NOTE — For definitions of the terms $G_{1,2}(f)$, $G_1(f)$ and $G_2(f)$, see the notes under *power spectral density* (5.1) and *cross-spectral density* (5.3).

5.5 statistical degrees of freedom : The number of independent variables in an estimate of some quantity.

NOTES

1 The number of degrees of freedom determines the statistical accuracy of an estimate.

2 When time-averaging is used in the analysis of random data, the effective number of statistical degrees of freedom is $n = 2BT$, where B is the effective filter bandwidth and T is the effective averaging time.

5.6 equivalent (static) acceleration (for a single degree-of-freedom system) : For a dynamic excitation, the steadily applied acceleration required to produce the same maximum relative displacement as the excitation does.

5.7 pseudovelocity : The product of the maximum relative displacement of an undamped single degree-of-freedom system and the angular natural frequency $2\pi f_n$.

5.8 aliasing error : An erroneous result in digital analysis of signals caused by having the maximum frequency of the signal greater than one-half the value of the sampling frequency (see 5.15) (which is sometimes referred to as the "Shannon frequency").

5.9 data block : The ordered collection of data points stored in the memory of a digital computer.

5.10 block size; block length : The number of records, words or characters in a block.

5.11 data points : The digital values obtained as a result of converting an analog signal.

5.12 frequency resolution : The reciprocal of the total time (see 5.13).

5.13 total time (in data processing) : The time needed to fill a data block.

5.14 sampling; sample (verb) : To obtain the values of a function for regularly or irregularly spaced distinct values from its domain.

NOTE — Other meanings of this term may be used in particular fields, for example in statistics.

5.15 sampling frequency : The number of samples taken in one second.

5.16 sampling interval : The time interval between two samples.

5.17 smoothing : An averaging process in which a data block is shifted and averaged.

NOTE — For example, smoothing over three data points is characterized by the relationship

$$\bar{x}_k = (x_{k-1} + x_k + x_{k+1})/3$$

Smoothing can be done in the time domain, the frequency domain and in histograms.

5.18 truncation (in vibration analysis) : The application of a record length which is too short to define the signal accurately.

5.19 data processing : A general term for the electronic or mechanical processing of original information.

5.20 data handling : Data processing which introduces no change in the original information, for example card sorting tabulation, storage, retrieval, coordinate transformation, etc.

5.21 data reduction : Data processing which causes changes in the original information, for example conversion from analogue to digital or *vice versa,* inversion of a function, averaging, etc.

5.22 real-time analysis : Signal processing to analyse parameters in real time.

5.23 Fast Fourier Transform (FFT) : A process where the computing times of complex multiplications/additions are greatly reduced.

5.24 quantizing : An analog-to-digital conversion where sampling quantizes every data point.

5.25 window function : A truncated function that is used for reducing the errors in processing weighted data points.

5.26 deterministic vibration : A vibration the instantaneous value of which at a certain time can be predicted from knowledge of its time history at an earlier time.

NOTE — In mathematical terms, if $f(t)$ for $t > t_0$ can be predicted from $f(t)$ for $t < t_0$, then the vibration represented by $f(t)$ is deterministic.

5.27 time history : The magnitude of a quantity expressed as a function of time.

5.28 stationary process : An ensemble of time histories such that their statistical properties are invariant with respect to translations in time.

5.29 strongly self-stationary : Term used to describe a random signal if all statistical properties determined by averaging a sample over a finite time interval are independent of the time at which the sample occurs.

5.30 weakly self-stationary : Term used to describe a random signal if the mean value and autocorrelation function determined by averaging a sample over a finite time interval is independent of the time at which the sample occurs.

5.31 ergodic process : A stationary process containing an ensemble of time histories where time averages are the same for every time-history.

NOTE — It follows that these time averages from any time history will then be equal to corresponding statistical averages over the ensemble.

5.32 random process; stochastic process : A set (ensemble) of time functions that can be characterized through statistical properties.

5.33 ensemble; set : A collection of signals.

5.34 autocorrelation function : For a quantity $x(t)$, the mean of the product of the value of the quantity at time t with its value at time $(t + \tau)$.

NOTES

1 The autocorrelation function can be expressed mathematically as

$$R(\tau) = \overline{[x(t)]\,[x(t+\tau)]} = \frac{1}{T}\int_0^T x(t)\,x(t+\tau)\,\mathrm{d}t$$

2 For a stationary random quantity $x(t)$ which persists for all time, T approaches infinity, that is

$$R(\tau) = \lim_{T \to \infty} \frac{1}{T}\int_0^T x(t)\,x(t+\tau)\,\mathrm{d}t$$

In practice, T is finite and the formula given in note 1 only gives an estimate with a certain statistical uncertainty which increases as T decreases.

5.35 cross-correlation function : For two quantities $x(t)$ and $y(t)$, the mean of the product of the value of one function at a time t and the value of the other function at a time $(t + \tau)$.

NOTES

1 The cross-correlation function can be expressed mathematically as

$$R_{x,y}(\tau) = \overline{[x(t)]\,[y(t+\tau)]} = \frac{1}{T}\int_0^T x(t)\,y(t+\tau)\,\mathrm{d}t.$$

2 See note 2 under *autocorrelation function* (5.34).

5.36 autocorrelation coefficient : For a quantity $x(t)$, the ratio of the autocorrelation function to the mean-square value of the quantity.

NOTE — The autocorrelation coefficient can be expressed mathematically as

$$\varrho(\tau) = \frac{R(\tau)}{R(0)} = \frac{\overline{[x(t)][x(t+\tau)]}}{\overline{x^2(t)}}$$

5.37 cross-correlation coefficient : For two quantities $x(t)$ and $y(t)$, the ratio of the cross-correlation function to the square root of the product of the mean-square values of the quantities.

NOTE — This can be expressed mathematically as

$$\varrho_{x,y}(\tau) = \frac{R_{x,y}(\tau)}{\sqrt{R_x(0)R_y(0)}}$$

where

$R_x(0) = \overline{x^2(t)}$;

$R_y(0) = \overline{y^2(t)}$;

$R_{x,y}(\tau)$ is as defined in 5.35.

At any delay τ, the cross-correlation coefficient satisfies

$$-1 \le \varrho_{x,y}(\tau) \le 1$$

5.38 effective bandwidth (of a specified band-pass filter) : The bandwidth of an ideal filter which has flat response in its passband and transmits the same power as the specified filter when the two filters receive the same white-noise input signal.

NOTE — The effective bandwidth may be measured by dividing the mean-square response of the filter to white-noise excitation by the product of the excitation spectral density and the square of the maximum transmission.

5.39 effective averaging time : The time required for an ideal integrator to yield the same parameter estimate as the averaging device employed.

5.40 confidence interval : For a normal distribution of measured data points, the range within which one value will lie with a given degree of probability.

Annex A
(informative)
Mathematical terms[1)]

A.1 reference : A quantity associated with a point in an element or system from which, or with respect to which, other similar quantities are measured. If the same reference is used generally throughout a system, it is called a **common reference.**

A.2 variable : A quantity that can assume a (finite or infinite) succession of values.

A.3 independent variable : A variable, such as time, the value of which is not determined by other variables.

A.4 dependent variable : A variable the values of which are determined by values of independent variables and parameters.

A.5 parameter : In a mathematical relationship, a quantity that describes a system characteristic. A parameter may be a variable in an equation, or it may be a "constant" that can be assigned different values.

A.6 function : The expression of a relationship between one dependent variable (the value of the function) and one or more independent variables and constants. For example a function of y, z and t.

A.7 proportional : One variable is said to be **directly** proportional to another variable if the ratio of the corresponding values of the variables is constant, and **inversely** proportional to another variable if the ratio of the reciprocal of one variable to the corresponding value of the other variable is constant.

A.8 linear function : One variable is said to be a linear function of another variable if changes in the first variable are directly proportional to changes in the second variable.

A.9 generalized coordinates : Quantities independent of one another, and necessary and sufficient for describing the configuration of a system.

A.10 vector : A quantity that is completely determined by its magnitude and direction.

A.11 scalar : Any quantity that is completely determined by its magnitude.

A.12 imaginary number : The product of a real number and $\sqrt{-1}$. The $\sqrt{-1}$ is normally represented by j or i.

NOTES

1 The positive value of the square root is implied.

2 In the vector, or geometric, interpretation, the multiplication of any complex number by i rotates it 90° counterclockwise about the origin, and multiplying it by – i rotates it 90° clockwise about the origin.

A.13 complex number :

(1) A number that contains both a real and an imaginary part.

(2) A number which represents a vector from the origin in a two-dimensional coordinate system.

NOTE — If a complex number is given as $z = x + iy$, where the imaginary part is given as iy, then x and y represent the component parts of the vector along the two orthogonal x and iy axes. The magnitude of the vector (or **absolute value** of the complex number) is $Z = (x^2 + y^2)^{1/2}$ and the direction of the vector (or the **argument** of the complex number) is $\Phi = \arctan y/x$. The complex number can also be expressed as

$$z = Z(\cos\Phi + i\sin\Phi) = Z e^{i\Phi}$$

A.14 phasor : A complex number the magnitude of which is the amplitude of the oscillation and the angle of which is the phase. For example, if it is desired to express a harmonic oscillation $Y(t) = Y_0 \cos(\omega t + \Phi)$ in complex notation, it would be expressed as follows:

$$Y(t) = \mathrm{Re}(Y_1 e^{i\omega t})$$

where

Y_1 is a complex quantity called the phasor, the magnitude of which equals Y_0 and the angle (or argument) of which is the phase angle (Φ);

Re means "real part of", but this is usually omitted as understood.

Y_1 is expressed as

$$Y_0 < \Phi$$

or

$$Y_0 \cos\Phi + i\, Y_0 \sin\Phi$$

where $i = \sqrt{-1}$.

Y_1 may also be written $Y_1 = Y_0 e^{i\Phi}$.

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1) The definitions included in this annex are essential to those working in the field of vibration and shock. However, as the formulations are also the concern of others, these definitions are not considered part of this International Standard.

A.15 argument (of a complex number) : The angle that fixes the direction of the complex number (vector). [See the note under *complex number* (A.13).]

A.16 modulus (of a complex number) : The absolute value of the complex number. [See the note under *complex number* (A.13).]

A.17 absolute value

(1) Of a real number, a positive number that has the same numerical value as a real number which may be of either sign.

(2) Of a complex number, the positive square root of the sum of the squares of the real and imaginary parts. [See the note under *complex number* (A.13).]

A.18 Fourier series : A series which expresses the values of a periodic function in terms of discrete frequency components that are harmonically related to each other.

NOTES

1 A non-periodic function can be represented by a Fourier series if the interval over which the function is defined is taken as the fundamental period of the series.

2 A Fourier expansion of $f(t)$ into a Fourier series is given by

$$f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

A Fourier expansion of $f(t)$ into a complex Fourier series is given as

$$f(t) = \sum_{n=1}^{\infty} c_n e^{in\omega t}$$

where

a_n and b_n are **Fourier coefficients**;

c_n is a **complex Fourier coefficient**;

ω is the angular frequency and is equal to $2\pi/\tau$, where τ is the fundamental period;

n is assigned only integral values.

The values of the Fourier coefficient are

$$a_0 = \frac{1}{\tau}\int_0^T f(t)\,dt$$

$$a_n = \frac{2}{\tau}\int_0^T f(t) \cos n\omega t\,dt \quad (n = 1, 2, 3, \ldots.)$$

$$b_n = \frac{2}{\tau}\int_0^T f(t) \sin n\omega t\,dt \quad (n = 1, 2, 3, \ldots.)$$

$$c_n = \frac{1}{\tau}\int_0^T f(t)\, e^{-in\omega t}\,dt \quad (n = \pm 1, \pm 2, \pm 3, \ldots.)$$

It can be shown that

$$c_{+n} = \frac{a_n - ib_n}{2} \quad c_0 = a_0 \quad c_{-n} = \frac{a_n - ib_n}{2}$$

The amplitude of each Fourier discrete frequency is

$$A_n = \sqrt{a_n^2 + b_n^2}$$

The Fourier phase angle is

$$\Phi_n = \arctan\left(\frac{b_n}{a_n}\right)$$

A.19 Fourier coefficients : The coefficients of the discrete harmonic components of a Fourier series. [See note 2 under *Fourier series* (A.18).]

A.20 Fourier transform; Fourier integral equation:

(1) **Direct Fourier transform** : The transformation of a non-periodic function of time (or other variable such as distance) into a continuous function of frequency (or other variable such as wave number).

(2) **Inverse Fourier transform** : The transformation of a continuous function of frequency (or other variable such as wave number) into its corresponding function of time (or other variable such as distance).

NOTE — If $f(t)$ is a non-periodic function of time, the complex form of the direct Fourier transform equation is:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-i\omega t}\,dt$$

The time function $f(t)$ is obtained from $F(\omega)$ by the following integration (the inverse Fourier transform equation):

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega) e^{i\omega t}\,d\omega$$

(The use of the factor $1/2\pi$ represents one formulation of the pair of transforms. In other formulations $1/2\pi$ appears in the direct rather than the inverse transform, or $1\sqrt{2\pi}$ may appear in each.)

Since $F(\omega)$ is in general in complex form, it can be written in terms of a real and an imaginary part:

$$F(\omega) = \mathrm{Re}[F(\omega)] + i\,\mathrm{Im}[F(\omega)]$$

where

$$\mathrm{Re}[F(\omega)] = \int_{-\infty}^{+\infty} f(t) \cos \omega t\,dt$$

$$\mathrm{Im}[F(\omega)] = \int_{-\infty}^{+\infty} f(t) \sin \omega t\,dt$$

Alternatively, the Fourier spectrum can be defined in terms of its absolute value and phase angle, $|F(\omega)|$ and $\Phi(\omega)$, respectively:

$$F(\omega) = |F(\omega)|\, e^{i\Phi\omega}$$

where

$$|F(\omega)| = \sqrt{\mathrm{Re}^2[F(\omega)] + \mathrm{Im}^2[F(\omega)]}$$

$$\Phi(\omega) = \arctan\left\{\frac{\mathrm{Im}[F(\omega)]}{\mathrm{Re}[F(\omega)]}\right\}$$

A.21 Fourier spectrum : A description of Fourier amplitudes as a function of frequency.

NOTE — Two Fourier spectra are required to define a function. These can either be spectra of the amplitudes of the real and imaginary parts of a Fourier spectrum or they can be a spectrum of the absolute amplitude values and a spectrum of the fourier phase angles. [See note 2 *under Fourier series* (A.18) and the note under *Fourier transform* (A.20).]

A.22 Fourier phase spectrum; phase spectrum: The description of Fourier phase angle as a function of frequency [See note 2 under *Fourier series* (A.18) and the note under *Fourier transform* (A.20).]

A.23 line spectrum : A spectrum the components of which occur at one or more discrete frequencies.

A.24 continuous spectrum : A spectrum the components of which are continuously distributed over a frequency range.

A.25 orthogonal functions : A set of functions, $\Phi_n(x)$, defined in an interval $0 \leq x \leq X$, is orthogonal in the interval if

$$\int_0^X \Phi_n \, \Phi_m^* \, \mathrm{d}x = 0, \quad \text{for } n \neq m$$

where

$\Phi_m{}^*$ is the complex conjugate of Φ_m.

A.26 deterministic function : A function the value of which can be predicted from knowledge of its behaviour at previous times.

A.27 superposition principle : A principle which states that the responses of a system to different excitations are additive. The superposition principle is valid only for linear systems.

A.28 process : A collection of signals. The term "process" rather than the term "ensemble" ordinarily is used when it is desired to emphasize the properties the signals have or do not have as a group. Thus, one speaks of a stationary process rather than of a stationary ensemble.

A.29 probability : An expression of the likelihood of occurrence of an event. The probability of occurrence of a particular event is generally estimated as the ratio of the number of occurrences of the particular event to the total number of occurrences of all types of events considered.

For a stationary random vibration, the probability that the magnitude will be within a given magnitude range is taken to be equal to the ratio of the time that the vibration is within that range to the total time of observation.

NOTES

1 It is required that a large number of events or a long observation time be involved in the probability determinations.

2 A unit probability means that the occurrence of a particular event is certain. Zero probability means that it will not occur.

3 The probability that the magnitude of a vibration will be within a given range is equal to the integral of the probability density function of that vibration integrated over the given range. [See *probability density* (A.30).]

A.30 probability density : As applied to vibration theory, at a specified vibration magnitude, the ratio of the probability that the vibration magnitude will be within a given incremental range, to the size of the incremental range, as the increment size approaches zero.

NOTES

1 The probability density can be expressed mathematically as

$$p(x_m) = \lim_{\Delta x_m \to 0} \frac{P(\Delta x_m)}{\Delta x_m}$$

or

$$p(x) = \frac{\mathrm{d}P(x)}{\mathrm{d}x}$$

where

$p(x_m)$ is the probability density at x_m;

Δx_m is an incremental range of magnitude beginning at a magnitude x_m;

$p(\Delta x_m)$ is the probability that the vibration magnitude will have a value between x_m and $x_m + \Delta x_m$.

2 The probability density $p(x)$ is the derivative of the cumulative probability distribution function, $P(x)$, with respect to x. (See A.34).

A.31 probability density function; probability density distribution curve : The probability density function, for vibration theory, is an expression of the probability density associated with a stated vibration.

The probability density distribution curve is a graphical representation of the probability density function.

NOTES

1 The functions $p(x)$ given under *probability density* (A.30) *normal distribution* (A.32) and *Rayleigh distribution* (A.33) are probability density functions.

2 The total area under the probability density curve is equal to unity.

A.32 normal distribution; Gaussian distribution; normal probability density distribution : A normal, or Gaussian, distribution has a probability density function equal to

$$p(x_p) = \frac{1}{\sigma\sqrt{2\pi}} \, \mathrm{e}^{-x_p^2/(2\sigma^2)}$$

where

σ is the r.m.s. value of, for instance, vibration magnitude [see *standard deviation* (A.37).]

x_p is the instantaneous vibration magnitude.

The mean value of the vibration is assumed to be zero.

A.33 Rayleigh distribution : A Rayleigh distribution has a probability density function equal to

$$p(x_p) = \frac{x_p}{\sigma^2} \mathrm{e}^{-x_p^2/(2\sigma^2)}$$

where

σ is the r.m.s. value;

x_p is the magnitude of positive maxima.

The maxima (peak values) of a narrow-band Gaussian random vibration have a Rayleigh distribution.

A.34 cumulative probability distribution function; probability distribution function : The cumulative probability distribution function, $P(x)$, represents the probability that the magnitude of the variable x (magnitude of the random vibration) will not be exceeded. It is the probability that the value of the variable x will be less than a specified value, X.

NOTE — The cumulative probability distribution function is equal to

$$P(x) = \int_{-\infty}^{x} p(u)\,\mathrm{d}u$$

where u is a dummy variable of integration for x.

A.35 mean value; arithmetic mean :

(1) Of a number of discrete quantities, the algebraic sum of the quantities divided by the number of quantities.

NOTE — The mean value, $\bar{x}$, is given by

$$\bar{x} = \frac{\sum_{n}^{x_n}}{N}$$

where

x_n is the value of the nth quantity;

N is the total number of discrete quantities.

(2) Of a function, $x(t)$, over an interval between t_1 and t_2, the mean value, $\bar{x}$, is given by

$$\bar{x} = \frac{\int_{t_1}^{t_2} x(t)\,\mathrm{d}t}{t_2 - t_1}$$

A.36 geometric mean (of two quantities) : The square root of the product of two quantities.

A.37 root-mean-square value; r.m.s. value :

(1) Of a set of numbers, the square root of the average of their squared values.

NOTE — The r.m.s. value of a set of numbers can be represented as

$$\text{r.m.s. value} = \left[\frac{\sum_n x_n^2}{N}\right]^{1/2}$$

where the subscript n refers to the nth number of which there are a total of N.

(2) Of a single-valued function, $f(t)$, over an interval between t_1 and t_2, the square root of the average of the squared values of the function over the interval.

NOTES

1 The r.m.s. value of a single-valued function, $f(t)$, over an interval between t_1 and t_2 is

$$\text{r.m.s. value} = \left[\frac{\int_{t_1}^{t_2} f(t)^2\,\mathrm{d}t}{t_2 - t_1}\right]^{1/2}$$

2 In vibration theory, the mean value of the vibration is equal to zero. In this case, the r.m.s. value is equal to the standard deviation, and the mean-square value is equal to the variance (σ^2). [See *standard deviation* (A.38) and *variance* (A.39).]

A.38 standard deviation : The root-mean-square (r.m.s.) value of the deviation of a function (or a set of numbers) from a mean value.

NOTES

1 The symbol σ is commonly used to represent the standard deviation.

2 For a set of numbers, the standard deviation is

$$\sigma = \left[\frac{\sum_n (x_n - \bar{x})^2}{N}\right]^{1/2}$$

where

the subscript n refers to the nth number;

N is the total number of numbers in the set;

$\bar{x}$ is the mean value of the set. [See *mean value* (A.35).]

3 If x is a single-valued function of t, its standard deviation over an interval between t_1 and t_2 is

$$\sigma = \left[\frac{\int_{t_1}^{t_2} (x - \bar{x})^2\,\mathrm{d}t}{t_2 - t_1}\right]^{1/2}$$

4 In vibration theory, if the mean value, $\bar{x}$, is taken to be zero, then the standard deviation is equal to the r.m.s. value.

A.39 variance : The square of the standard deviation.

NOTE — In vibration theory, where the mean value is zero the variance is the mean-square value of a variable representing the magnitude of a vibration. [See note 3 under *mean-square value* (A.40).]

A.40 mean-square value : The mean-square value of a function (or set of numbers) over an interval is equal to the mean of the squared values of the function (or set of numbers) over that interval.

NOTES

1 The mean-square value is the square of the r.m.s. value.

2 In vibration theory, when the mean value is zero, the mean-square value is the variance. [See *variance* (A.39).].

If the mean value is not zero, then

$$\psi^2 = \sigma^2 + \bar{x}^2$$

where

ψ^2 is the mean-square value;

σ^2 is the variance;

$\bar{x}$ is the mean value.

Annex B

(informative)

Auxiliary terminology[1]

B.1 signal :

(1) A disturbance variation of a physical quantity used to convey information.

(2) The information to be conveyed over a communication system.

B.2 distortion (of a signal) : An undesired change in the waveform.

NOTE — For an acceleration, for example, the distortion, d, is usually expressed in percentage terms as

$$d = \frac{\sqrt{a_{\text{tot}}^2 - a_1^2}}{a_1} \times 100$$

where

a_1 is the r.m.s. value of the acceleration at the driving frequency;

a_{tot} is the total r.m.s. value of the acceleration applied (including the value of a_1).

B.3 resolution : The resolution of a system for measuring motions is the smallest change in input (dispalcement, velocity, acceleration, strain, or other input quantity) for which a change in output is discernible.

B.4 time constant; relaxation time : The time taken by an exponentially decaying quantity to decrease in magnitude by a factor of 1/e = 0,367 9.

NOTE — The discharge of an electrical capacitance through a resistance is proportional to

$$\mathrm{e}^{-t/RC}$$

where

t is time;

R is resistance in ohms;

C is capacitance in farads;

e is the base of natural logarithms;

and the product, RC, is the **time constant** or **relaxation time.**

B.5 ground; earth :

(1) The conducting mass of the Earth, or a conductor connected to it through a very small impedance.

(2) A conductor that is considered to have zero electrical potential. The electrical potential of the Earth is usually taken to be zero.

B.6 ground wire; earth wire : A wire connected to a ground terminal.

B.7 ground loop; earth loop : The closed electrical circuit formed by the connection of a ground wire to several ground terminals at different locations.

B.8 input impedance (of an electronic amplifier) : The electrical impedance between the input terminals.

NOTE — The input impedance may be affected by the output load; if so, the output load should be specified.

B.9 output impedance (of an electronic amplifier) : The electrical impedance between its output terminals.

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[1] The definitions included in this annex are essential to those working in the field of vibration and shock. However, as the formulations are also the concern of others, these definitions are not considered part of this International Standard.

NOTE — The output impedance may be affected by the source impedance at the input; if so, the source impedance should be specified.

B.10 operational amplifier : An amplifier which includes a feedback loop which maintains a specific relationship between the output terminals and the input terminals.

NOTE — Depending upon the type of feedback and other auxiliary circuitry, the amplifier can be used to perform various functions, such as integration, differentiation, charge amplification, etc.

B.11 charge amplifier : An amplifier which presents an output that is proportional to the total electrical charge presented to the input.

B.12 cross-talk : The signal observed in one channel due to a signal in another channel.

B.13 frequency response : The output signal expressed as a function of the frequency of the input signal. The frequency response is usually given graphically by curves showing the relationship of the output signal and, where applicable, phase shift or phase angle as a function of frequency.

B.14 filter; wave filter : A device for separating oscillations on the basis of their frequency. It introduces relatively small attenuation to wave oscillations in one or more frequency bands and relatively large attenuation to oscillations of other frequencies.

NOTE — Electrical filters, and some mechanical filters employing resonances, may amplify selective frequency bands and thus provide filter action.

B.15 pass band (of a band-pass filter) : The frequency band between the upper and lower cut-off frequencies.

B.16 low-pass filter : A filter which has a single transmission band extending from zero frequency up to a finite frequency.

B.17 high-pass filter : A filter which has a single transmission band extending from some critical or cut-off frequency, not zero, up to infinite frequency or, in practice, above the highest frequency of interest.

B.18 band-pass filter : A filter which has a single transmission band extending from a lower cut-off frequency greater than zero to a finite upper cut-off frequency.

B.19 nominal bandwidth (of a filter); **bandwidth** : The difference between the nominal upper and lower cut-off frequencies. This difference can be expressed

a) in hertz;

b) as a percentage of the pass-band centre frequency; or

c) as the interval between the upper and lower nominal cut-offs in octaves.

B.20 nominal upper and lower cut-off frequencies (of a filter pass-band); **cut-off frequency** : Those frequencies above and below the frequency of maximum response of a filter at which the response to a sinusoidal signal is 3 dB below the maximum response.

B.21 constant-bandwidth filter : A filter which has a bandwidth of constant value when expressed in hertz. It is independent of the value of the centre frequency of the filter.

B.22 proportional-bandwidth filter : A filter which has a bandwidth that is proportional to the centre frequency.

NOTE — Octave bandwidth, one-third octave bandwidth, etc, are typical bandwidths for proportional-bandwidth filters.

B.23 octave : The interval between two frequencies which have a frequency ratio of two.

NOTE — The interval, in octaves, between any two frequencies is the logarithm to the base 2 (or 3,322 times the logarithm to the base 10) of the frequency ratio.

B.24 one-half octave; half octave : The interval between two frequencies which have a frequency ratio of $2^{1/2}$, or 1,414. [See the note under *octave* (B.23).]

B.25 one-third octave; third octave : The interval between two frequencies which have a frequency ratio of $2^{1/3}$, or 1,259 9. [See the note under *octave* (B.23).]

NOTE — For certain kinds of acoustical measurements it is convenient to space the frequencies in fractions of an octave, but for extensions into the infrasonic and ultrasonic ranges it is convenient to use powers of 10. These two conflicting requirements can be satisfied adequately for most purposes because $2^{1/3} = 1{,}259\,9$ is very nearly equal to $10^{1/10} = 1{,}258\,9$, the discrepancy being less than 0,1 %. This means that ten successive intervals of 1/3 octave are very nearly equivalent to a ratio of 10 in frequency.

B.26 one-tenth decade : The interval between two frequencies which have a frequency ratio of $10^{1/10}$ or 1,258 9.

NOTES

1 The difference between 1/10 decade and 1/3 octave is less than 0,1 % [see the note under *one-third octave* (B.25).] The two bandwidths can therefore be considered equivalent for practical purposes.

2 The interval, in decades, between any two frequencies is the logarithm to the base 10 of the frequency ratio.

B.27 octave-bandwidth filter : A band-pass filter for which the pass-band is one octave, i.e. the difference between the upper and lower cut-off frequencies is one octave. [See *proportional-bandwidth filter* (B.22).]

B.28 one-third-octave filter; third-octave filter : A band-pass filter for which the difference between the upper and lower cut-off frequencies is one-third octave. [See *proportional-bandwidth filter* (B.22) and the note under *one-third octave* (B.25).]

B.29 narrow-band filter : A band-pass filter for which the pass-band width is relatively narrow.

NOTE — Whether or not a bandwidth can be considered narrow is dependent upon the circumstances. For shock and vibration work, it is normally 1/3 octaves or less.

B.30 wide-band filter : A band-pass filter for which the pass-band is relatively wide.

NOTE — Whether or not a bandwidth can be considered wide is dependent upon the circumstances. For shock and vibration work, it is normally greater than one octave.

B.31 centre frequency; nominal pass-band centre frequency : The geometric mean of the nominal cut-off frequencies of a pass-band.

NOTE — The geometric mean is equal to $\sqrt{f_1 f_2}$, where f_1 and f_2 are the cut-off frequencies.

B.32 band-elimination filter; band-reject filter: A filter that provides a large attenuation for one frequency band, and little loss for frequencies outside of this band.

B.33 tracking filter : A band-pass filter (usually narrow-band) the centre frequency of which can be made to follow a quasi-sinusoid of varying frequency.

B.34 crystal filter : A narrow-band filter for which the piezoelectric crystal operating at a resonance frequency is the principal element of the filter.

B.35 magnetostrictive filter : A narrow-band filter for which a magnetostrictive element at a resonance frequency is the principal element of the filter.

B.36 peak-notch filter : An electrical filter which is adjusted so as to change the signal applied to a power amplifier driving an electrodynamic vibration generator, such that it will eliminate relative maxima and minima which appear in the spectrum of the generator output.

NOTE — The relative maxima and minima in the spectrum are usually caused by the mechanical reactions of mechanical elastic systems that are subjected to the vibration.

B.37 equalization (of an electrodynamic vibration generator system) : The adjustment of the gain of the electrical amplifier and control system so that the ratio of the output vibration amplitude to the input signal amplitude is of constant value (or given values), throughout the required frequency spectrum.

Annex C
(informative)

Schema for arranging vibration terms

The terms in this vibration terminology are arranged in accordance with the logic shown in figure C.1. It is based on practical rather than theoretical considerations, on the manner in which records of vibrations (time histories) are collected and how the information extracted from these records is treated. The two principal categories of vibrations are based on whether a particular vibration is deterministic or random.

Deterministic vibration is the class of vibrations for which the instantaneous value of the vibration at a specified time is determined precisely by its time history (i.e. the record of its instantaneous values) for time values earlier (i.e. less) than the specified time. Random vibration is the class of vibrations for which the instantaneous value of the vibration at a specified time cannot be determined by its time history.

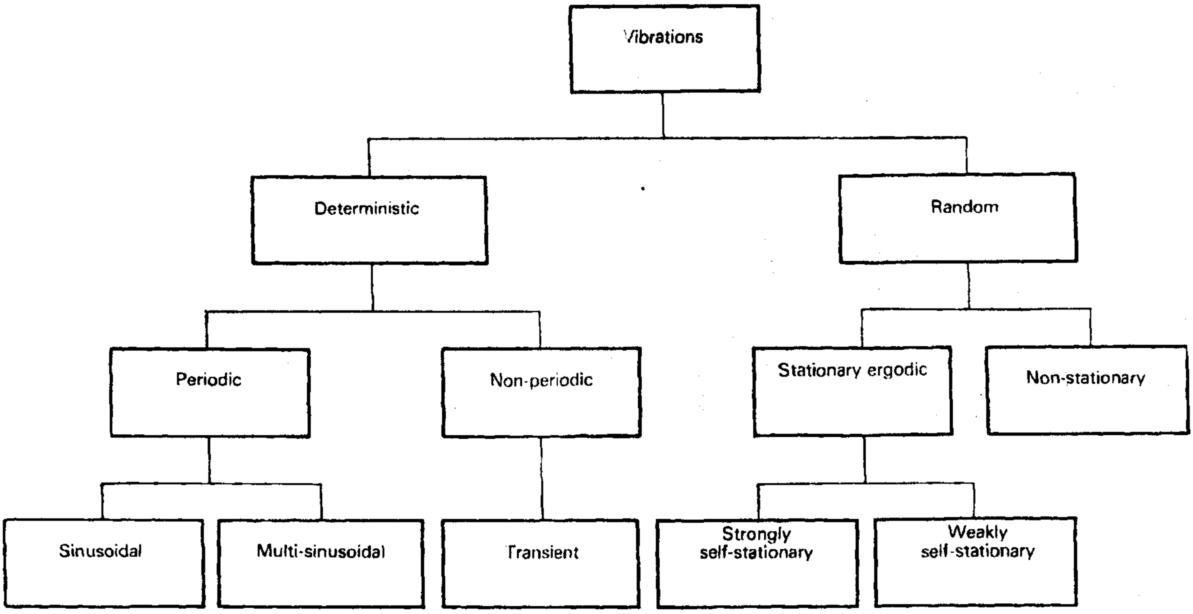

Figure C.1 — Schema for types of vibration

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This Indian Standard has been developed from Doc : No LM 04 (0390).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Printed at New India Printing Press, Khurja, India